State-of-the-Science in Mobile Health for Diagnostic, Treatment, Public Health, and Health Research

Santosh Kumar and Wendy Nilsen

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Santosh Kumar, University of Memphis
Wendy Nilsen, National Institutes of Health & National Science Foundation
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Abstract: Creative use of new mobile health information and sensing technologies has the potential to reduce the cost of health care and improve health research and outcomes. By virtue of being with the user most of the time in daily life and by assessing novel health parameters, mHealth is poised to bring significant improvements to diagnostic, treatment, public health, and health research. Coupled with these unprecedented benefits are unforeseen sources of uncertainty and lack of control on data collection on which health decisions may need to be made. This article provides an overview of various potential benefits of mHealth and the potential pitfalls that may have legal implications.

1. Introduction
We use the definition of mobile technology in (Kumar et al., 2013a), which defines it as wireless devices and sensors (including mobile phones) that are intended to be worn, carried, or accessed with the person during normal daily activities. Mobile health (mHealth) is the application of mobile technology for assessment of improvement of human health. Due to rapid advances in mobile sensing and computing, it is now feasible to assess and/or intervene on disease, movement, images, behavior, social interactions, environmental toxins, hormones, and other physiological variables (Kumar et al., 2013b). Consequently, mHealth has the potential to advance research, prevent disease, enhance diagnostics, improve treatment, reduce health disparities, and increase access to health services and lower healthcare costs in ways previously unimaginable (Spruijt-Metz et al.).

Unprecedented growth and adoption of mobile phones (at 6 billion), and growing penetration of smartphones (65% in the US), promises to amplify the reach and impact of mHealth. The number of mHealth applications in the area of smartphone apps is growing rapidly (already 97,000 in 2013) (Greatcall). By 2013, there were 247 million downloads by consumers, 59% of patients in emerging markets used at least one mHealth app, and 62% of physicians and 71% of nurses now use smartphones or tablets (Rupp, 2013). These apps are only one small part of the mHealth field. This interest and potential translates into growing business opportunities. The mHealth market that is $1.3 billion today is projected to be $20 billion by 2018. These estimates point to unprecedented growth, with tremendous implications for the health of a majority of patients in the very near future. We are witnessing the entry of new industry segments, with very little prior health experience, into mHealth. They include numerous technology startups, as well as mobile giants from the hardware, software and telecom industries. Devising an appropriate legal and regulatory framework for nascent mHealth can help maximize the benefits and minimize adverse impact on the health of consumers, as well as on the finances of providers and insurers.
This article summarizes potential current uses of mHealth and points to potential pitfalls, highlighting the legal implications for mHealth. Figure 1 below organizes the usage of mHealth for various health purposes, which are described in greater detail in Section 2. Section 3 points to safety and efficacy issues that need to be addressed in mHealth.

Continuum of mHealth tools

Figure 1: Major categories of mHealth impact include Diagnostic, Treatment, Public Health, and Health Research.

2. State-of-the-science in mHealth

In this section, we discuss applications of mHealth in improving diagnostics, treatment, public health, and health research. The goal is to provide several examples that together can provide a comprehensive view of the possibilities so we can understand their potential legal implications. It is not meant to be a comprehensive survey of the field nor a complete coverage of the available devices.

*mHealth System Concept:* In an mHealth system, data collected by various sensors on the body, in the phone, or in the infrastructure (e.g., wireless thermostat) can all send data to the mobile phone via wireless channels. These data can then be processed locally or offloaded to the cloud for real-time processing. Actions can thus be taken based on the data collected in real-time by the phone (to trigger notifications), or by the cloud (potentially via clinical decision support systems at a health care provider). In the following, when we describe mHealth devices, they are assumed to operate under the above architecture.
2.1. Diagnostics
mHealth devices are improving diagnostics via novel ways of assessing various health states. By enabling patients to conduct many of these assessments remotely, the number of assessments can greatly increase without greatly increasing costs. In addition to measuring health states, mobile devices can also provide exposures that may be determinants of changes in health states. Exposure assessments include environmental exposure (e.g., via GPS), activity and behaviors (e.g., via accelerometry), social exposure (e.g., via microphone), visual exposure (e.g., via smart eyeglasses), and electronic exposure (e.g., via social media data). Further, for those systems that work with a patient, mHealth devices that provide data and feedback can also empower patients to take charge of their health. Sharing of data with providers can increase the confidence and accuracy in clinical decision making. In the following, we provide examples of mHealth devices that can help with assessment of biologics, imaging, and physiology.

Self-testing of blood glucose via a mobile device that connects to smartphones has been available commercially (Geoga et al., 2014). Other advances in mobile biologics have gone far past glucose. Researchers have created a chip-based micro NMR unit that includes smartphone powered analysis of a range of bio-markers, DNA, bacteria, viruses and pharmacology (Lee et al., 2008).

Recent advances in microfluidics have also led to the emergence of microfluidic chips that can perform lab-quality HIV tests for use in low-and middle-income countries [Malone, 2013]. Similarly, advances in lens free microscopy have led to mobile attachments that can be used for assessment of malaria, tuberculosis, HIV, or even blood cell counts (Coskun and Ozcan, 2014).

Other biological systems use implantable sensors to track functioning overtime (Wright and Burgess, 2012). Still others use sensors in gum bases (similar to children’s washable tattoos) to monitor biological activity (Jeong et al., 2014). Advances in portable imaging have led to the development and commercialization of mobile devices for assessment of eyeglass prescription, cataract formation, and even retinal imaging (Pamplona et al., 2010). Finally, numerous teams have brought a mobile ultrasound unit to market that also attaches to a mobile phone and can be used for abdominal screening, assessment of fetus health, and triage, among several other applications (Smith et al., 2010).

Assessment of physiology such as blood pressure, heart rate, blood oxygen, respiration, etc. that are part of vital signs can now be done via mobile units with high enough quality that some of these devices have been approved by the Food and Drug Administration for use in hospital settings (Food and Drug Administration, 2013).

Measurement of accelerometry has been available for activity monitoring for decades. Accelerometry is often thought of in conjunction with physical activity for weight loss, but recent work has begun employing it for assessment of function in studies of stroke patients and multiple sclerosis. A recent development is the integration of several other sensors in a wrist
watch so that it is conveniently wearable for long durations. Currently, these devices have begun with activity monitoring, heart rate and blood pressure, although the quality of the measurements remains unknown. In the near future, commercial device manufacturers (e.g., Apple and Samsung) promise to monitor pulse rate, hydration levels, glucose levels, and blood pressure, in addition to activities such as physical activities, sleep behavior, etc. Again, the quality of these measures remains to be seen (Pogue 2014).

In summary, the wearable mobile sensors are gradually moving diagnostics from the hospital to the field setting and from care providers to patients. Consequently, they promise to increase the frequency of diagnostics performed and hence the number of health decisions made. This may, in turn, give rise to new legal challenges. For example, if mHealth-assisted health decisions are taken by care providers on the basis of noisy data collected in unsupervised field environment by non-trained care providers (e.g., patients themselves), who will be responsible for adverse decisions? More importantly, if the health decisions are made by patients themselves on the basis of data collected by mobile devices and information displayed by the mobile devices, who bears the responsibility for adverse decisions? These and other scenarios need to be generated and discussed by the community in order to build a solid legal foundation for mHealth.

2.2. Treatment
In addition to improving diagnostics, mHealth has a potential to make tremendous contributions to improve treatments. Diagnostics advances can directly improve clinical decision making by providing assessment data across a variety of health parameters from the field to complement the one-time assessments done in the lab.

In addition, simple sensors such as accelerometers worn by patients as well as those embedded in mobile gaming devices are being used to deliver physical therapy and occupational therapy. By monitoring the posture and gait of the user via motion sensors as well as via cameras, these devices can monitor compliance with physical therapy exercises and make suggestions for better compliance (e.g., Dobkin et al., 2011). Monitoring adherence to a treatment regimen via mobile devices also makes it easier to track compliance and rate of recovery remotely and intervene when and where needed (e.g., Lester et al., 2010).

The potential of mobile and wireless health technologies to continuously monitor chronic medical conditions around the world, as well as to implement disease management plans that capitalize on this expanded information is another growing area of activity. Chronic disease conditions have been recognized in the developed world as a major source of morbidity and mortality. Similarly, in low- and middle-income countries, chronic disease is increasingly being cited as an emerging problem and a major component of disease burden. Because there is no known cure for chronic disease, medical management must extend over the patient’s life time. A fundamental characteristic of most chronic disease is that the medical profession manages the disease rather than cures it. Self-management of chronic diseases via mHealth system can ease the burden on healthcare and improve disease management. An example of these systems is self-management for diabetes using a mobile health system that includes glucose measurements using mobile devices, adherence monitoring and encouragement using
reminders, tracking of trends and generation of alerts using data analytics, and data sharing with care provider for informed clinical decisions (Quinn et al., 2011).

Other treatment systems focus on areas such as heart disease, drug and alcohol dependence, asthma and sickle cell disease. Still other mobile systems attempt to help users stop smoking. Finally, recent work has begun bringing therapy for mental health disorders to mobile systems. This is critical because many of these issues require coaching, support and tools in real time and will not wait for an office visit (Gustafson et al., 2014).

Wellness is an area that has seen an immense growth in the app world. The largest category of the 97,000 apps available for smartphones is that for wellness. It includes weight loss, physical activity, and sleep monitoring. These apps are sometimes paired with infographics of data on servers for self-reflection, goal setting and progress towards goals, and recommendations. By combining assessments of physical activity, social activity, and sleep patterns, mobile applications promise to help patients with serious mental illnesses track their mental well-being and receive timely interventions when and where needed (Matthews et al., 2014). Other applications combine these sensor measurements with self-reports for self-management of health and behavior (Hsieh et al., 2013).

Each treatment or wellness application promises to improve the health of the user. This is based on the hypothesis that better monitoring will lead to better management, better outcomes and reduced disease burden. But, this hypothesis is yet to be tested in the majority of diseases (Kumar et al., 2013a, Green and Glasgow, 2006). Each claim must be supported with appropriate evidence. What constitutes the appropriate level of evidence has changed over the years. Should all mHealth devices be required to submit evidence of efficacy; that their use does not result in adverse events or even that they employ best practices? A legal framework that determines responsibility in case of an adverse outcome should take into consideration various issues including the ones highlighted in the preceding.

2.3. Public Health
Even in the United States, ensuring access for all people to high quality healthcare remains an issue (Woolf and Aron, 2013). Access can be hampered by transportation and location (e.g., rural areas have less healthcare options than urban), socioeconomic status (access to insurance and ability to pay) and language/acculturation concerns (Woolf & Aron, 2013). Although in the United States some of these issues are a target of the Patient Protection and Affordable Care Act (http://www.gpo.gov/fdsys/pkg/BILLS-111hr3590enr/pdf/BILLS-111hr3590enr.pdf), mHealth has been championed as a way to address access, especially in low- and middle-income countries (Free et al., 2013).

mHealth has the potential to increase access to underserved population groups because of the rapid adoption of mobile devices: 90% of American adults and 78% of teenagers now have a cell phone, with more than half now being smartphones (Pew Research, 2014). In contrast to the Internet digital divide that limited the reach of computerized health behavior interventions for lower socioeconomic groups, mobile phone use has been rapidly and widely adopted among...
virtually all demographic groups (Pew Research, 2014). This means that many homes that could not easily or comfortably access healthcare can now identify and access information and services through their phones. For health information, this is especially important because technology can allow us to generate information in a way that is tailored to individual needs. For example, a decision support tool to help people understand the need for/risks of mammography can use a layered approach that allows anything from videos with experts to visualizations of risk to professional articles on the topic. Thus, mHealth reduces the need for a one-size-fits-all program of information. This customization of information provides for much better tailoring of information. Although mHealth, when used for such education and outreach, may not have a direct impact on health, it does have significant impact on the finances of the sponsor and hence demonstration of cost-effectiveness and the broader reach requires evidence. It also may require new forms of evaluation that range from user-centered design and usability to efficacy.

mHealth and social media have also changed the way that health professionals can think about public health surveillance. For example, mHealth applications (Fraser et al., 2012) have been used around the world to track health status as trained workers or volunteers collect and enter local health data through the application. The data are aggregated in the cloud to make them available to communities and/or predict health trends. These mHealth applications have the potential to reduce cost, increase efficiency and even provide better data through more comprehensive data collection. These data can then be used to direct interventions and guide health policy for affected areas. More recently, the focus has turned to even more public ways of collecting health surveillance data. This use of public data from Facebook or Twitter or even consumer facing applications like Google Flu is now a focus of research and may provide a usable source of surveillance data in the future. Although reception of these new surveillance models has been embraced by the research community, there are concerns about the use of these social media data beyond their intended purpose. This is especially so if major public health decisions such as targeting care activities, are based on these new sources of information.

mHealth tools are also now allowing public health officials to track medications as they move through the system. For example, the m-Pedigree program aims to prevent counterfeiting of medications in low- and middle-income countries (Curioso and Mechael, 2010), while the Proteus Raisin system uses sensors for individual dose monitoring of medications to increase appropriate use of these medications in the United States (Au-Yeung et al., 2010). Tracking systems generally use sensors that allows providers to see when and where drugs are being consumed. While tracking counterfeit medications offer few concerns, the goal of tracking medication usage may evoke privacy concerns. These concerns may arise over questions about the usage of the data for legal purposes (as in the case of opioids) or over forced adherence to medications in those who are non-compliant with treatment recommendations.

All of these uses highlight the ways in which mHealth may enhance public health efforts. With appropriate regulatory guidance, these efforts should yield evidenced-based methods for increasing access to care and information, as well as tracking and monitoring that should enhance the health of the population and reduce healthcare expenditures. The evidence
requirements to demonstrate the effectiveness and efficiency of these methods may feed into formulation of new legal frameworks (or revision of existing ones) for regulating the use of this information for public health decision making.

2.4. Health Research

Each of the above areas (diagnostics, treatment, and public health) involve health research in both development and evaluation prior to its adoption for use by patients and providers. In addition to being the subject of health research, mHealth is increasingly being used to improve health research due to its distinct advantages. These advantages can be grouped into three major categories: 1) temporally rich data for measurement and discovery; 2) real-time surveillance and interventions; and 3) access to underserved populations for participation in research studies.

Temporally-rich data: As noted throughout this paper, the recent proliferation of wireless and mobile technologies provides the opportunity to connect information in the real-world via wearable sensors, fixed sensors (e.g., grocery loyalty card information or National Oceanic and Atmospheric Association’s weather data) embedded in the environment, and pair this information with conventional health data available from electronic health records, genomic databases and biomarker information. These data have the potential to yield new insights into the factors that lead to disease either through targeted experiments or mining these temporally-rich data. Because most mobile devices (including phones and sensors) are carried on the person and are collecting data throughout the day, researchers are now able to begin to think about big data at the level of the individual (Estrin, 2014). In fact, the fusion of streaming biological, physiological, social, behavioral, environmental, and locational data now can dwarf the traditional genetics and electronic health records “big data” datasets. These data are important for answering the difficult questions of gene-environment-behavior interplay in health and disease, understanding the developmental origins of disease, and providing data to inform the development of treatments and prevention programs that are preemptive, personalized and adaptive over time. The merging of real-world and real-time data with conventional records can allow researchers to expand our understanding of health and disease in a way that was previously unimaginable. Fusing these vast stores of data also creates profound legal and regulatory challenges (see privacy and security section) because triangulation of these data make it very difficult to de-identify and ensure research participants can keep their identity private (Kim et al., 2013).

Real-time surveillance and interventions: New sensor technology is now expanding the abilities for real-time surveillance in research. As noted earlier, there are now a wide array of new sensors for monitoring various aspects of health, which will allow researchers to explore changes in health status before these issues would come to the notice of patients or traditional healthcare providers. This will allow for better health surveillance and provide data that can be used for adaptive, personalized interventions that provide the needed treatment in real-time. For example, recent research (Gustafson et al., 2014) has examined the effect of real-time monitoring and just-in-time intervention with people who are alcohol dependent. This study showed that monitoring and application of psychological and social support in real-time was
significantly more effective in reducing relapse than treatment as usual. Should these real-time interventions show increasing efficacy, there will be a move to implement them in the community, especially in disorders that have proved expensive or difficult to treat outside of the highly monitored randomized clinical trial environment. While dissemination and implementation of efficacious treatments is as it should be in evidenced-based medicine, these real-time interventions may be perceived as denying autonomy to people who do not see the need for their treatment or who are not in treatment willingly (such as in some cases of mental health or chemical dependency treatment).

Access to underserved populations: mHealth tools have the potential to transform clinical trials. Remote monitoring and sensing can allow researchers to conduct remote clinical trails; that is, recruit and follow patients without the need or cost to transport them to a research or healthcare setting. This is important because past research suggests that the vast majority of ill people are not treated in academic medical centers, which are the sites for most published research (Green and Glasgow, 2006). By reducing the need for researchers and participants to be in close proximity and reducing the burden of participation, mHealth can increase sample representativeness and the quantity and quality of follow-up data, all at decreased cost. Another benefit is that previously underserved groups can now participate in research because of the rapid adoption of mobile devices. These remote trials require new human subjects’ protection and regulatory policy to support their use.

3. Efficacy & Safety

Decisions made using data collected from mHealth devices will affect the health and wellbeing of patients and the finances of patients, providers, and insurers. Novel sources of data bring novel sources of inaccuracies, uncertainties, and variability. Therefore, mHealth brings new challenges in ensuring the efficacy of treatment decisions and safety of patients (including those challenges emanating from potential loss to patient privacy). We discuss some of these issues below.

3.1. mHealth BIGDATA

While mHealth brings tremendous potential to advance diagnostics, treatment, public health, and health research via passive collection of data from mobile devices in the natural environment of patients, it also brings unforeseen challenges. Data collected from the uncontrolled natural environment, by untrained health care professionals (i.e., patients themselves in many cases), under a variety of circumstances can have uncertainties embedded in them that have never been encountered before. Several issues can affect the quality of data collected by sensors including loss or loosening of sensor attachment, errors in placement, and losses in the wireless transmissions (Kumar et al., 2013b). Computational methods to identify these errors and screening methods to separate out good quality sensor data from unacceptable quality data are the subjects of ongoing research.

The health decisions made from mHealth data not only have to deal with uncertainty and unforeseen variability in the quality of sensor data, they also have to deal with known and unknown inaccuracies in machine learning models that are applied on sensor data to arrive at
decisions. Identifying, characterizing, and modeling these uncertainties and incorporating them in the data-to-decision process is sometimes referred to as mobile sensor BIGDATA and it is an active area of research. Although this research will reduce the uncertainties and improve the suitability of sensor-derived decisions to individual patients via personalization, there will always remain some level of uncertainty. Given the role of multiple parties in the data-to-decision process (sensor manufacturer, mobile phone manufacturer, mobile phone software developer, application developer, patient, care provider, etc.), a legal framework is needed to determine the responsibilities in case of adverse decisions.

3.2. Privacy & Security

It is clear that many of the strengths of mHealth research (the ability to reach large and underserved samples and collect continuously streaming data on a range of potentially sensitive and possibly illegal behaviors and events) also drive privacy and security concerns. It is important to note that these topics, as well as confidentiality, are all separate, yet connected issues in protecting research participants and patients. For example, the National Committee for Vital and Health Statistics describes the differences as: “Health information privacy is an individual’s right to control the acquisition, uses, or disclosures of his or her identifiable health data. Confidentiality, which is closely related, refers to the obligations of those who receive information to respect the privacy interests of those to whom the data relate. Security is altogether different. It refers to physical, technological, or administrative safeguards or tools used to protect identifiable health data from unwarranted access or disclosure” (Cohn, 2006). These issues are further complicated by federal regulations governing personal health information, as well as sensitive information concerning alcohol, drug use or mental health.

In the United States, privacy is considered an essential freedom. It is the right of individuals to determine for themselves when, how, and to what extent personal information is communicated to others. Because privacy targets the human side of information protection, the solutions to these issues target the humans using the technology. At the highest level, patients currently regulate who can access their personal health information through consent. The consent provides participants with appropriate knowledge of what data are being collected, how they are being stored and used, their rights to the data, and the potential risks of disclosure.

Unfortunately, technological literacy in the United States limits peoples’ understanding of the true risks and befits of mobility. For example, research has shown that a majority of Americans (78%) consider information stored on their mobile phones to be as or even more private than the information stored in their personal computers (Urban et al., 2012). Understanding of the information content of sensor data is even more limited (Raij et al., 2011). For instance, from seemingly innocuous electrocardiogram data, stress level (Plarre et al., 2011) and cocaine use (Hossain et al., 2014) can be inferred. From respiration data, smoking (Ali et al., 2012) and conversation episodes (Rahman et al., 2011) can be detected. And, from smart watch data, not only physical activity, but eating and smoking behaviors can also be extracted (Parate et al., 2014). The science on what behaviors or health states can be extracted from which sensor data is evolving as research progresses. With this progress, efforts are also needed to educate patients and to develop appropriate policies to safeguard patient privacy.
As changes in technological literacy take time to implement, health systems and researchers implementing mHealth tools will need to do their best to develop systems that enhance participant privacy. More specifically, this means building mHealth systems that allow research participants some control over the data, whether this be control over which data are collected or which data are released to the research team. Researchers will need to be very explicit about the data they are collecting and what control the participants will have over them. This also means that mHealth researchers should be very thoughtful over what research data are collected.

As noted earlier, security refers to the safeguards, techniques and tools used to protect against the inappropriate access or disclosure of information. Research suggests that often legitimate users of a system may be the likely cause of impaired security because they overlook rules or because the costs of their actions is underestimated or not understood (Besnard and Arief, 2004). Thus, when it comes to securing data, researchers should keep in mind the prevention of the most likely breaches, such as leaving mobile devices unsecured, sharing passwords or leaving them written on notes, accessing sensitive information in public areas using open WiFi networks, or even losing one’s mobile device. While outsiders may also intentionally attempt to access information or attempt to figure out identity or location from intercepting communications, many of the breaches are preventable through having a high quality security plan that pays special attention to the most common and simplest reasons for data losses.

In addition to prevention, the goal of an effective security protocol is to protect participant identity and secure data in such a way that if someone unauthorized were to gain access, they would be unable to link the data with a particular person or with other data that is being sent. This is especially true because while no single source of data may be identifiable, the combination of multiple sources of data may make identifiable linkages possible. This is especially important in mHealth as information is often transmitted at a high frequency and transferred over wireless networks, which can be more susceptible to monitoring and interception than internet networks (Luxton and Kayl, 2012). Encryption of data is a key component of security that allows for the protection and preservation of anonymity, but must be done prior to the transfer of data. This process hides the content of a message while it is in transit and the original message can only be seen through a process called decryption. A “key” is needed in the process of encrypting and decrypting and in healthcare settings. According to federal HIPAA and HiTech Act regulations this key must be 128-bits to offer sufficient security (Department of Health and Human Services, 2013). Although encryption is an important part of many privacy and security protocols, since many factors that result in data breaches are directly related to the humans using the device, encryption should be considered one component of a protocol to protect and secure mHealth data.

In summary, while security of wireless mHealth systems may borrow significant knowhow from existing works and best practices, mHealth brings novel challenges to ensuring patient privacy, which call for new efforts in both research and policy domains.
4. Conclusion

In conclusion, the world of mHealth is exploding with promise across the areas of diagnostics, treatment, and public health. Although the goal of collecting large amounts of data to drive better decision-making and intervening in real-time both have a basis in science, to date there has been less research in this area than would be suggested by the explosion of new devices and apps. In order to ensure that these untested apps and devices do not replace evidenced-based or gold-standard treatments, new regulatory and legal frameworks are needed that balance innovation and safety.

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